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Sustainability and resilience: A review of definitions, relationships, and their integration into a combined building assessment framework

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ABSTRACT

Every year, the United States is faced with billions of dollars in damages and large numbers of deaths due to natural hazards. Resilience to these hazards has become a growing theme in sustainable design and the current global discourse on climate change adaptation. Coping with the challenges of earth's ever-shifting climate contextualizes the importance of resilience in sustainable development. To achieve greater resilience at a minimum environmental cost, the literature suggests developing a coherent sustainability and resilience framework. This review discusses the definition of sustainability and resilience and the relationship between the two concepts in order to examine the possibility of establishing such a combined framework. Studying the relationship between the sustainability and resilience points to some similarities between the two paradigms but also highlights key differences that may impede their integration. Most existing studies advocate the incorporation of resilience indicators into sustainability metrics and believe it to be technically possible. The major finding of this review is that the integration process requires developing a new combined assessment tool or a thorough refinement of current sustainability frameworks to include resilience indicators that were not initially included. For such a unified framework to be established successfully, the active involvement of different stakeholders in all stages is necessary.

1. Introduction

Problems regarding energy consumption and climate destabilization are central to almost every other issue facing the United States. Trade, defense and the well-being of the nation rely on reliable infrastructure and energy supplies with an ability to thrive despite inherent natural hazards. According to the U.S. Energy Information Administration [1], the building sector- which includes both residential and commercial-accounts for 39% of total U.S. energy consumption (Fig. 1). The United States has also experienced more significant losses in terms of life, property and economic activity due to natural disasters over the past 10 years (Fig. 2). The failure of the United States to establish a long-sighted energy policy over the past four decades, coupled with a lack of focus on methods to mitigate the impact of climate change, have put the country on an "unsustainable" course [3], and led to the propagation of developments that are "vulnerable" to these hazards [4]. Green building rating systems such as Leadership in Energy and Environmental Design (LEED) developed by the U.S. Green Building Council (USGBC) and Green Globes by Green Building Initiative, have been used to ensure improved sustainability in construction and development for more than a decade, and are among the most widely used sustainability assessment systems in the world. Despite this, even these frameworks have been criticized by scholars including Plumblee & Klotz [5] and Champagne & Aktas [6] for not including hazard resilience indicators. New York City, for example, with one of the largest collection of LEED-certified green buildings in the world, suffered more than $19 billion in losses as a result of Hurricane Sandy [7]. As reported by Zolli and Healy, these green buildings are "designed to generate lower environmental impacts, but not to respond to the impacts of the environment" [8]. However, recent years have seen a growing interest in pushing the design standards beyond code minimum requirements in order to "achieve targeted performance goals for resilient post-hazard functionality" [9]. As an example, the FEMA Building Science Branch produced P-798 Natural Hazards and Sustainability for Residential Buildings to "retain or improve natural hazard resistance while incorporating green building practices" [10]. In this regard, research suggests that there is a need for combining sustainability and resilience indicators into a unified assessment framework. While the majority of the

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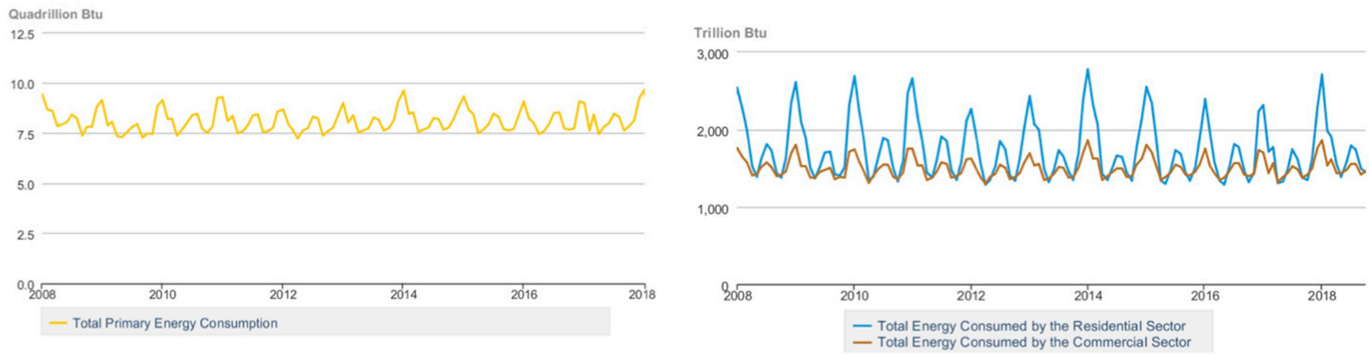

Fig. 1. a) 2008–2018 Total U.S. Primary Energy Consumption (including embodied and operating energy). b) 2008–2018 Energy Consumption by Residential and Commercial Sectors. Source: U.S. EIA. www.eia.gov/totalenergy/data/browser/?tbl=T02.01#/?f=M.

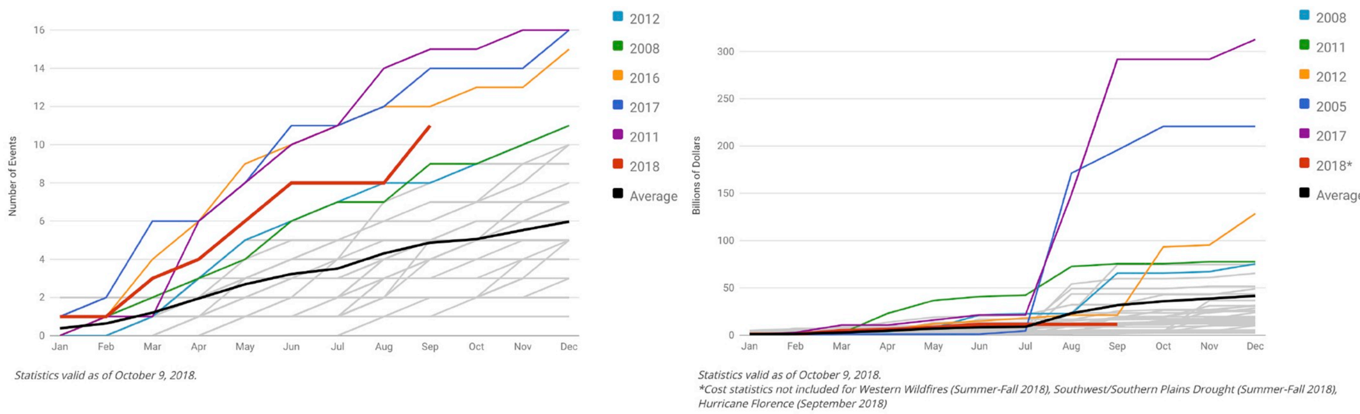

Fig. 2. a) 1980–2018 Year-to-Date United States Billion-Dollar Disaster Event Frequency. b) 1980–2018 Year-to-Date United States Billion-Dollar Disaster Event Cost. Source [2]: https://www.ncdc.noaa.gov/billions/.

literature supports the unification of sustainability and resilience frameworks or balancing sustainability with structural integrity [6,7,11], some indicate the existence of tensions between the two concepts [12]. It has been argued that resilience is not necessarily an objective of its own [13], or that not all resilience indicators are in compliance with sustainability goals [14]. Holling and Walker [15] note that: "[r]esilience, per se, is not necessarily a good thing. Undesirable system configurations (e.g. Stalin's regime, collapsed fish stocks) can be very resilient, and they can have high adaptive capacity in the sense of reconfiguring to retain the same controls on function". The objective of this review is to:(1) provide an in-depth understanding of the definitions of sustainability and resilience and the relationship between the two concepts; (2) study the merger of these two concepts into a single tool, and (3) identify the challenges of integrating resilience into sustainability assessment frameworks.

2. The review procedure

2.1. Aim

The study presented here reviews the definition of sustainability and resilience and the relationship between the two concepts. Additionally, we sought to provide evidence in the literature in support or opposition to the combination of the two concepts, while also describing the challenges of incorporating resilience indicators into sustainability assessment frameworks.

2.2. Search process

The search process was conducted in the Web of Science and Engineering Village databases. To control the quality and uniformity of data the document type was limited to "reviews," "articles" and "books/book chapters" and the language was selected as "English." As the concept of resilience emerged in the literature around 1970, the timespan was set from 1970 to 2018.

The keywords for Web of Science were (((sustainable OR green OR high-performance OR LEED) near/0 (building OR design OR construction OR buildings)) OR housing) AND (resilience OR resiliency OR hazard resilience OR resilient) AND (incorporating OR incorporated OR integrating OR integrated). Web of Science uses "Near/0" when no word between the two key terms is desired. Searching Web of Science resulted in 102 records. The search conducted via the Engineering Village, adopting "expert" mode, took the following input, (((sustainable OR green OR high-performance OR LEED) AND ((building OR design OR construction OR buildings) OR housing) AND (resilience OR resiliency OR hazard resilience OR resilient) AND (incorporating OR incorporated OR integrating OR integrated))). This search yielded 220 results (Table 1).

Once the data search was completed, 27 additional records identified through hand-searching the references of the original 322 articles were added. 49 duplicate records were removed and a total of 300 records were selected for the screening process. Titles and abstracts were then screened and irrelevant results were excluded. 125 full-text records were selected for eligibility check. After reading the full texts records, a total of 57 papers were included in this study (Fig. 3).

2.3. Finding evaluation

After selecting the final 57 publications included in the study, each was thoroughly assessed and evaluated based on coverage of definitions of sustainability and resilience, the relationship between the two concepts, or the process of integrating them into a cohesive framework and

Table 1
Search inputs and results in both databases.

Database	Web of Science	Engineering Village
Topic	(((sustainable OR green OR high-performance OR LEED) near/0 (building OR design OR construction OR buildings)) OR housing) AND (resilience OR resiliency OR hazard resilience OR resilient) AND (incorporating OR incorporated OR integrating OR integrated)	(((sustainable OR green OR high-performance OR LEED) AND ((building OR design OR construction OR buildings) OR housing) AND (resilience OR resiliency OR hazard resilience OR resilient) AND (incorporating OR incorporated OR integrating OR integrated)))
Type	Article, Review, Book, Book Chapter	Journal Article, Book Chapter
Time Span	1970-2018	1970-2018
Language	English	English
Results	102	220

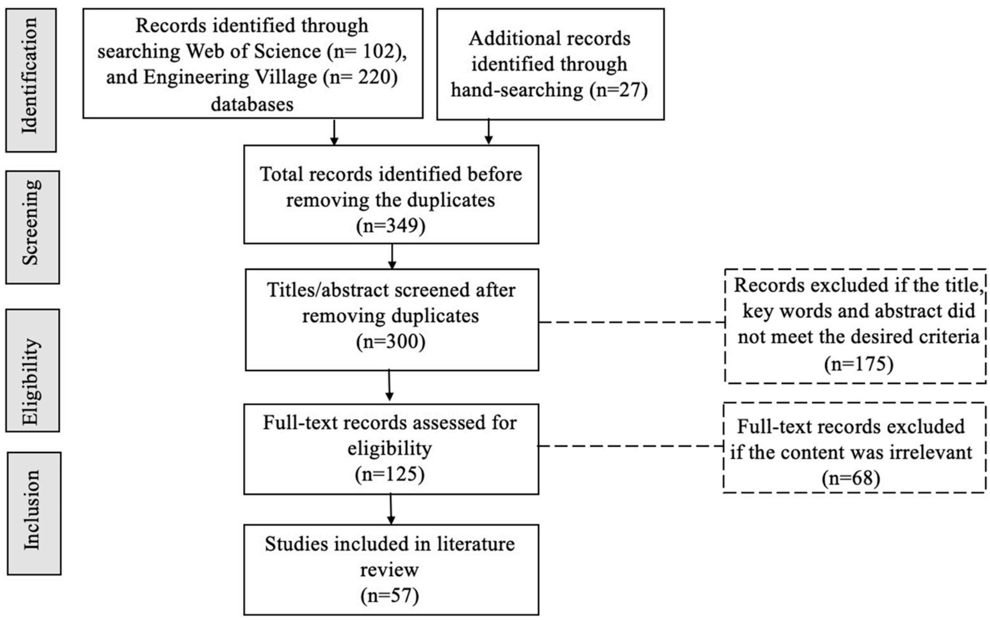

Fig. 3. Literature review search strategy. Based on [16].

challenges of developing such a framework. Table 2 depicts the search records of the literature and their relationship to the key indicators of this study. Fig. 4 summarizes the number of records for the key search indicators.

3. Results

3.1. What is sustainability?

Despite being a well-established term, there are some vague and generic interpretations of the concept of sustainability, most commonly in areas in which the environmental origins of sustainability are of secondary importance [19,20]. In such domains, the narrowest definition of sustainability – "to maintain the status quo and to not disappear"– seems to be serving the purpose [19,21]. Sustaining the status quo, therefore, sometimes translates as the core notion of sustainability being the tendency to mitigate or avoid change [12,19]. Other examples of such broad definitions of sustainability are "anything that ensures the well-being of societies and environment" [19] or "an ethical concept that things should be better in future than they are at present" [22]. Thinking of sustainability as "longevity" is also another way to approach the concept, meaning "the longer a system can be maintained, the more sustainable it is" [19,20]. The most cited definition of sustainability, however, is derived from the 1987 Brundtland Commission Report which describes sustainable development as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This classic definition of sustainable development, with slight modifications and minor alternations, is still being widely used in a variety of fields. For example, sustainability is defined by Leach et al. as "the capability of maintaining over indefinite periods of time specified qualities of human well-being, social equity, and environmental integrity" [23]. This variation is also alluded to by Lew et al. [19] who describe the main goals of sustainable development as "protecting and maintaining natural and cultural resources for the future and mitigating change" and highlight some tangible efforts of sustainability such as "reduc[ing] the consumption of carbon and other natural resources, increase[ing] biodiversity, protect[ing]tangible heritage artifacts, and revitalize[ing] intangible cultural traditions".

At the First International Conference on Sustainable Construction held in Tampa, Florida, in November 1994, the Conseil International du Bâtiment (CIB), an international construction research networking organization, defined sustainable construction as "…Creating and operating a healthy built environment based on resource efficiency and ecological design" and articulated seven Principles of Sustainable Construction as follows: reducing resource consumption, reusing resources, using recyclable resources, protecting nature, eliminating toxins, applying life-cycle costing, focusing on quality [24]. The U.S. Green Building Council (1993) also identifies sustainable building practices and design considerations that could be summarized into the LEED categories: location and transportation, sustainable site, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, innovation, and regional priority.[1]

This study looks at sustainability from the perspective of level three

[1] See Ref. [24], p98, for more detail on Design Considerations and practices for Sustainable Building.

Table 2
Search records included in the study based on their coverage.

Area of Research	References	Number of Records
Definition-related Publications	[2], [5], [7], [9], [14], [18], [20], [21], [24-28], [31, 32], [34], [37], [40], [42-45], [48, 49], [51-54], [57], [59-62]	33
Relationship-related Publications	[8], [13], [35], [38,39], [60]	6
Integration-related Publications	[1], [3], [10, 11], [14-16], [21, 22], [36], [39, 40], [46, 47], [50], [56-58]	18
Total Number of Records		57

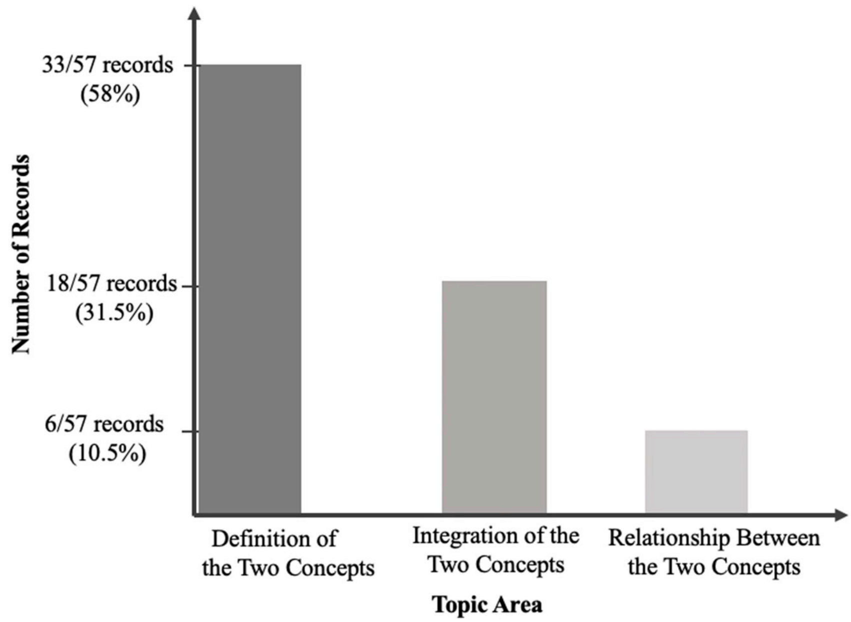

Fig. 4. Search Records Included and their Percentage.

sustainability assessment frameworks (i.e., BREEAM, LEED). Also known as whole building assessment systems, level three tools, according to Athena Sustainable Materials Institute, provide comprehensive coverage of environmental, economic, social and other issues relevant to sustainability and use a mix of objective and subjective data. These assessment tools usually yield certificates and claim to be incorporating LCA tools [25].

3.2. What is resilience?

The concept of resilience is gaining momentum in academia (Fig. 5) and practice in response to “the damage caused by the overexploitation of resources” [12] which causes the earth's climate to change and deviate from historical climate data [6]. The National Oceanic and Atmospheric Administration [2] reported sixteen weather and climate disasters –including Hurricanes Harvey, Irma, and Maria– in 2017 across the US with losses exceeding $1 billion each. “These events resulted in the deaths of 362 people and had significant economic effects [over 300 billion dollars] on the areas impacted” [2]. The number of environmental and geophysical natural hazards are also predicted to go up due to the effect of global climatic changes [27]. Whereas the core idea of sustainability is to reduce negative impacts on the environment to avoid changes, resiliency is about adaptation to change [12]. Although greening practices and lowering pollutants are the primary concerns of sustainability, the emergence of resilience thinking due to increasing intensity and frequency of natural catastrophes, requires buildings to be not only sustainable but also resilient [14]. We found three major areas in which resilience has gained substantial traction, namely, the academic literature, government regulations and among private and non-governmental organizations.

3.2.1. Resilience in the academic literature

Originating from Holling's 1973 research on ecology and behavior of ecological systems, resilience was first introduced to the academic literature as “a measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables” [28]. Due to the broad nature of the many fields affected by the topic, the essence of resilience remains elusive [7]. Despite its inexplicit character, resilience is now being applied to a variety of disciplines with some conceptual similarities and a shared understanding of “the responses to shocks, surprises, unforeseen or hazardous disturbances” [29]. The popular definition of resilience is “having the capacity to persist in the face of change, to continue to develop with ever-changing environments” [26]. The earlier studies on resilience refer to “the return rate to equilibrium upon a perturbation,” or sometimes define it as “bouncing-back after disturbance or recovery time, or recovery to what you were before” [26]. Resilience is also defined as the “capacity of a system to absorb disturbance and reorganize while undergoing [a] change to retain essentially the same function, structure, and identity” [30]. Extending the concept to other fields, social resilience is defined by Adger [31] as the “ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change”. Zolli and Healy [8] define resilience in relation to human society as the “ability to help vulnerable people, organizations, and systems persist, perhaps even thrive, amid unforeseeable disruptions”.

In social and ecological fields, the concept of resilience pivots around “persistence through continuous development, innovation, and transformation to attain new and better-adapted configurations” [32]. This approach considers systems to be dynamic and in flux. Such systems “adapt or transform to accommodate shocks or changes in variables [32]. Looking from this perspective, current interpretations of resilience focus on adaptability and dynamic nature of self-adjustment,

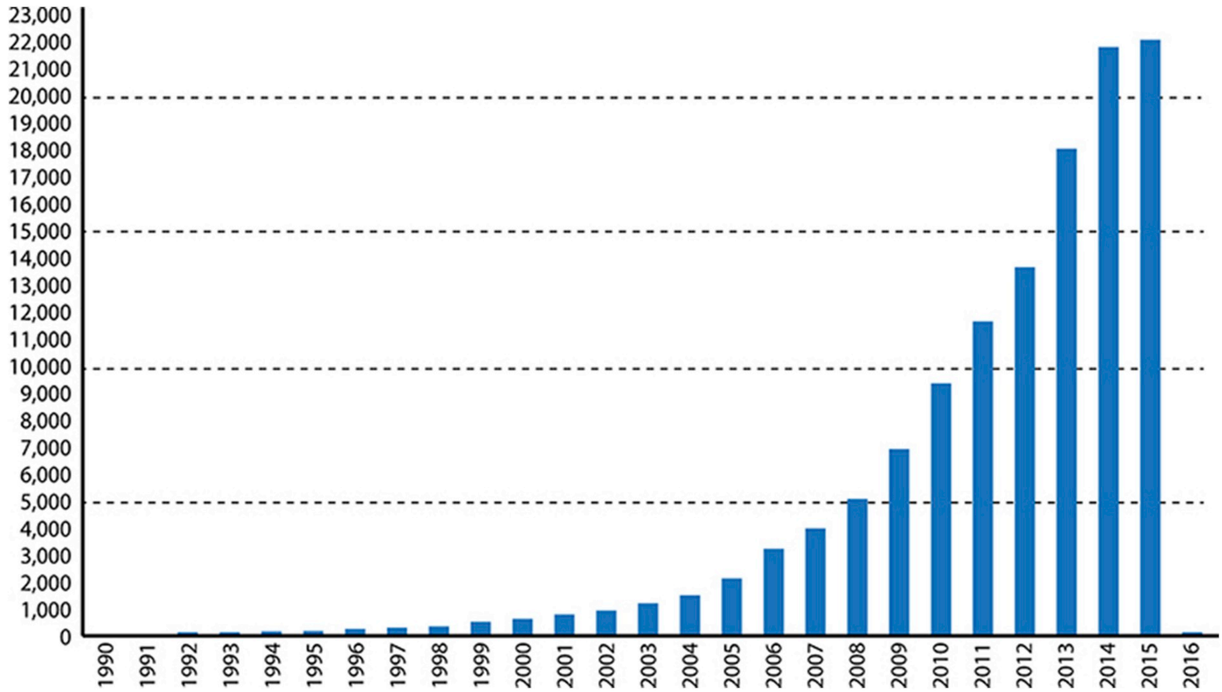

Fig. 5. The number of annual citations attributed to resilience in relation to the environment (environmental studies, environmental sciences, ecology). Source: [26].

what Folke [26] refers to as "persisting with change on the current path of development." This is in contradiction with the more static nature of engineering resilience which considers resilience as a "return to a prevent status" rather than capturing the adaptive or transformative aspects of resilience [32]. As Brand and Jax [17] state, the original ecological perception of resilience has changed considerably due to the following reasons:

- The concept is being used for many different purposes and with a vast extension.
- Resilience as a concept includes normative dimensions.
- There is an ambiguity in the use of the concept.
- The original ecological aspects of resilience are being overshadowed by social, political and institutional dimensions.
- Resilience is conceived more as a perspective than a well-defined concept.

Brand and Jax [17] also reviewed different definitions of resilience within sustainability studies and classified resilience into three main categories based on the specific degree of normality, namely: descriptive, hybrid and normative concepts. As for subcategories of the three key concepts, they also provided 10 definitions of resilience. In another study, Xu et al. [29] examined the contribution of resilience for sustainability science and provided seven definitions of resilience as psychological, engineering, ecological, social economic, social-ecological resilience and resilience engineering. Due to the similarities and overlaps found in these two categorizations, we propose a unified classification system which combines various categories in one single coherent classification framework (Fig. 6).

Despite the wide application of resilience in multiple disciplines, an accepted definition of resilience has not been achieved within the AEC industry [33]. There are some inconsistencies around the concept of resilience, for example, urban planners think of resilience as recovery from an event or a disaster, while the insurance sector sees resilience through the lens of risk and hazard mitigation [34]. In this regard Zhao et al. [7] define resilience as "the capacity of a residential structure to absorb external stresses; retain function; reduce industrial risk; and help vulnerable people, organizations, and systems persist."

3.2.2. *Resilience in government regulations*

Apart from the scholarly literature on resilience, the concept has gained popularity in both international and national politics [35]. A good example is the Hyogo Framework for Action (HFA), developed by the United Nations International Strategy for Disaster Reduction (UNISDR). HFA came out of the World Conference held in Kobe, Hyogo, Japan in 2005 to substantially reduce disaster losses by 2015 by building the resilience of nations and communities to disasters [36]. The Intergovernmental Panel on Climate Change, also defines resilience as: "The capacity of systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation" [37].

Resilience has also gained ground in policy documents at the national level and was officially recognized in the US national doctrine in 2010. From the administrative and political perspective, it was a part of the 2010 National Security Strategy to meet the full range of threats and hazards including "terrorism, natural disasters, large-scale cyber attacks, and pandemics" [38]. The National Security Strategy of the United States defines resilience as "the ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption" [38]. The Obama Administration issued two Presidential Policy Directives, PPD-8 and PPD-21 to put resilience into effect on a national level. PPD-8 National Preparedness (2011) sees catastrophic natural disasters as a threat to national security and defines resilience as, "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies" [39]. PPD-21 Critical Infrastructure Security and Resilience (2013) gives a revised definition of resilience as, "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions, [including] deliberate attacks, accidents, or naturally occurring threats or incidents" [40]. PPD-8 resulted in releasing the country's first-ever National Preparedness Goal by FEMA in 2011. "The Goal sets the vision for nationwide preparedness and identifies the core capabilities and targets necessary to achieve preparedness across the following five mission areas: prevention, protection, mitigation, response and recovery" [41]. The Department of Homeland Security (DHS) also defines resilience as "the ability to resist, absorb, recover from or

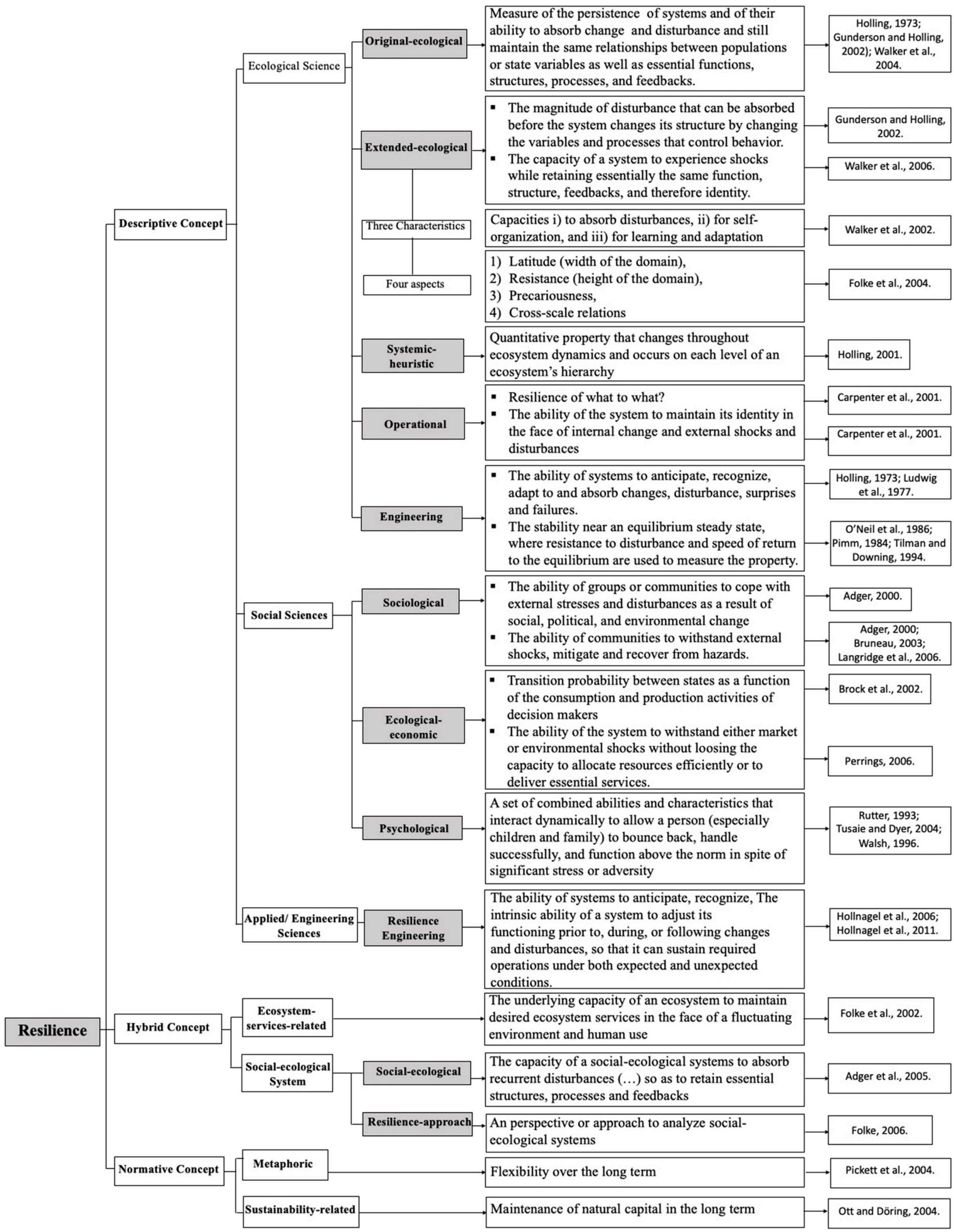

Fig. 6. Definitions of Resilience in different disciplines. (Modified from Ref. [17]; Xu et al.

successfully adapt to adversity or a change in conditions” [42]. In 2014, DHS released the Quadrennial Homeland Security Review with five missions, among which- Mission 5- Strengthening National Preparedness and Resilience, is devoted to resilience as evidenced by the name of the mission itself [41].

3.2.3. Resilience in non-governmental organizations

In addition to the policies developed by the federal government, some private organizations also took action in response to the potential chaos brought on by shifting climate conditions. For example, the United Nations Development Programme (2005) as part of the United Nations’ mission to maintain international order, defines resilience as “the tendency to maintain integrity when subject to disturbance” [43]. Also, the Resilience Alliance (RA) -developed in 1999 from The Resilience Network-emphasizes resilience as an essential property of the linked social-ecological systems [44]. The Resilience Alliance (RA) has contributed with insights on resilience in social-ecological systems, developed resilience thinking and also linked it to development agendas [26]. The RA describes resilience as "the capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning, and adaptation [28,30,45].

Another such institution, The Resilient Design Institute (RDI), states its mission as “advancing sustainability through a focus on resilience in our buildings and communities” [46]. RDI [46] defines resilience as “the ability to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance. It is the capacity to bounce back after a disturbance or interruption”. The Green Building Initiative (GBI), is also another organization that advocates sustainable thinking and application of green building best practices. The GBI's [47] definition of resilience is “the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.” To contribute to the resiliency of the built environment, the GBI promotes the Green Globes which provides third-party certification of green building best practices and resilience consideration” [47]. Fig. 7 summarizes the definition of resilience in the academic literature, government regulations and among private and non-governmental organizations.

The present study is concerned with the latter set of definitions of resilience, as a fundamental function of “buildings, landscapes, communities, and regions to respond to natural and manmade disasters and disturbances—as well as long-term changes resulting from climate change—including sea level rise, increased frequency of heat waves, and regional drought” [46]. The reason for selecting this definition is the specific focus it has on green buildings and increasing sustainability by focusing on resilience. It is also due to the fact that this paper views a resilient building as not just an isolated project but a building that sits within a community of diverse structures.

3.3. The relationship between sustainable development and resilience

Despite the fact that resilience and sustainability have been appearing together in a variety of fields as a new area of research, several studies indicate the lack of a conceptual framework for consolidating the two concepts together [14,48]. While many consider sustainability and resilience as slightly nuanced perspectives on the same phenomenon, others see them as distinct conceptual paradigms with sustainability's conservation goals being in opposition to the adaptation goals of resilience [19]. Lew et al. [19] link this confusion between the concepts with two reasons. Firstly, the lack of a solid definition and conceptualization of the two terms; and secondly, the fact that the two concepts share some essential assumptions, methods, and goals such as life-cycle analysis, structural analysis, and socioeconomic analysis [49]. Also, both concepts focus on survivability or as [50] argues, on the persistence of a system over time, under normal operating conditions and in response to disturbances. Their joint connection to global political trends, such as climate change mitigation, link them to the development of global frameworks and multilateral agendas [51]. To examine the feasibility of creating a unified framework for sustainability and resilience, the relationship between the two needs to be investigated.

The literature has drawn many different connections between the concepts of sustainable development and resilience. According to Derissen et al. [13]; the literature on the relationship between sustainability and resilience can be grouped into two main categories. The first category, as Lizarralde et al. [12] also stated, considers the two concepts synonyms and often uses them almost interchangeably. For example, Holling and Walker [15] argue that “a resilient socio-ecological system is synonymous with a region that is ecological, economically, and socially sustainable.” Similarly, Levin et al. [52] consider resilience as the preferred way to think about sustainability in natural and social systems. The second group of literature sees resilience as a necessary precondition for sustainability and sustainable development. Among these, are studies by Arrow et al. [53] which point out that "[…] economic activities are sustainable only if the life-support ecosystems upon which they depend are resilient", or Perrings [54] stating that "[a] development strategy is not sustainable if it is not resilient". Lebel et al. [55] also argue that "[s]trengthening the capacity of societies to manage resilience is critical to effectively pursuing sustainable development." Others believe “for a building in a hazard-prone zone, one cannot talk of sustainability if the structure does not show adequate resilience against natural hazards” [56].

To identify synergic implementation of sustainability and resilience Marchese et al. [20] conducted a literature review of 17 published management frameworks and found three dominant themes describing either:

- resilience as a component of sustainability,
- sustainability as a component of resilience, or
- sustainability and resilience as separate conceptual objectives.

The first framework considers resiliency as an integral part, or as Lew et al. [19] put it, as “a key indicator” of sustainability. In other words, “increasing the resilience of a system makes that system more sustainable, but increasing the sustainability of a system does not necessarily make it more resilient” [20]. It also asserts that without resilience a system can only possess fragile sustainability [57]. Another common perspective, represented by framework two, holds resilience as the ultimate objective of the system so that “increasing the sustainability of a system makes the system more resilient, but increasing the resilience of a system does not necessarily make that system more sustainable” [20]. The third framework considers sustainability and resilience as two separate yet complementary concepts with no hierarchical structure [6,7,20]. In this system “resilience does not fundamentally contribute to sustainability, nor does sustainability fundamentally contribute to resilience” [20].

3.4. Developing an integrated sustainability and resilience framework

As resilience is gaining more attention due to the increasing effect of natural hazards, its close interaction with sustainability in the built environment is becoming more pronounced. Federal Emergency Management Agency (FEMA), for example, designed P-798 Natural Hazards and Sustainability for Residential Buildings in 2010 to, “retain or improve natural hazard resistance while incorporating green building practices” [58]. There are already voluntary code-plus programs and guidelines for hazard-resistant construction which could be utilized in sustainable development projects [4]. Programs such as Resilience-Based Earthquake Design Initiative (REDi), FORTIFIED or the USRC -with *Resilience is the New Sustainability* as its slogan-have

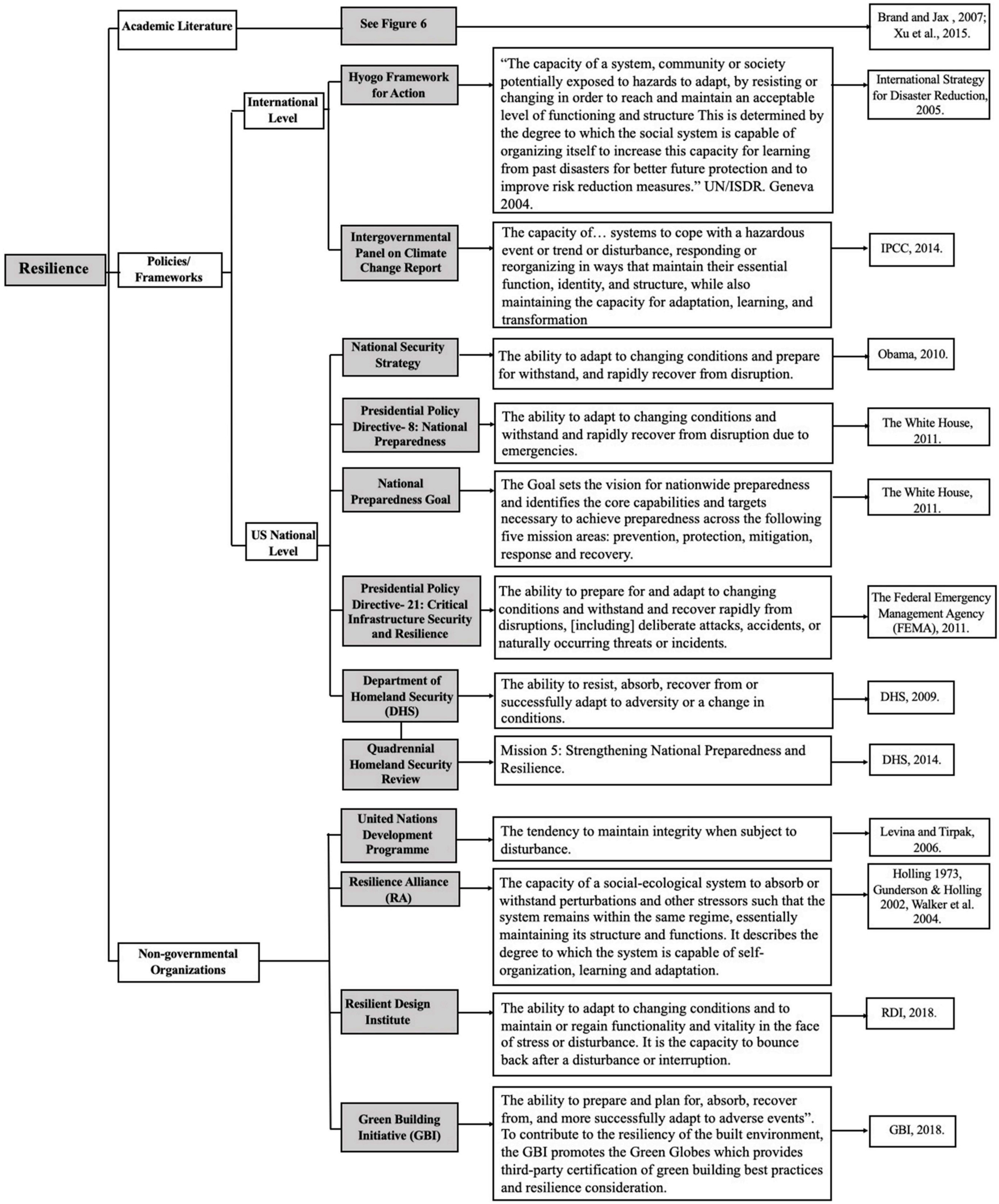

Fig. 7. The proposed three levels of defining resilience.

been developed to rank building resilience and hazard performance [9]. The Resilient Design Institute (RDI)-founded in 2012- also offers practical solutions for enabling buildings and communities to survive in the face of global climate change. Some studies have also investigated the merger between the resilience and sustainability assessment frameworks and highlighted "a need to conceptualize the integration of resiliency into sustainability" [48].

Matthews et al. [4]; for example, conducted a multi-level analysis of

11 Sustainability Assessment Framework (SAF)s to compare their level of resilience coverage. The following conclusions have been derived from their study:

- Resilience is not systematically integrated throughout SAFs (ranging from 17.9% in Envision as the highest overall coverage to 5% in LEED for Homes and LEED NC as the lowest coverage).
- Limited coverage of hazards (8 out of 11 frameworks include three or fewer hazards). Flood is the most incorporated hazard included in all 11 SAFs, followed by the earthquake and surge as second most included hazards.
- Flood-related measures other than those concerned with stormwater runoff are not consistently incorporated across all SAFs.
- There are weaknesses in resilience coverage, such as failing to consider the impacts of climate change, that may lead to the design of structures and communities vulnerable to extreme events.

Similarly, Achour et al. [27] studied ten international sustainability assessment tools and reported the Japanese CASBEE® and the German DGNB as the only tools in which resilience has been integrated. They also suggested CASBEE® to be used as a model for incorporating sustainability and resilience as it fulfills the required engagement of technical, strategic, social and political stakeholders. Additionally, Champagne & Aktas (2016) studies the existing overlaps between resilient design principles and the LEED v4. Their research revealed that the LEED v4 does not address about half of the identified principles. To fill this significant gap, they recommended prioritizing regional resilience credits that correspond to the nature of the hazards in a given location. Looking from a different perspective, Phillips et al. [14] evaluated four existing resilience frameworks. They examined 88 strategies and classified them into five resilience themes: risk avoidance, passive survivability, durability and longevity, redundant systems, and response and recovery. Regarding their contribution to sustainability, these strategies were classified into three qualitative groups: positive, negative, or conditional strategy. 35 of them were positive, 14 were negative, and 39 were conditional. "Those focused on risk avoidance, passive survivability, and response and recovery were largely conducive to sustainability goals … Conversely, strategies that focused on durability and longevity, as well as redundant systems, tended to have divergent resilience and sustainability performance" [14].

The literature also indicates a set of tensions between sustainability and resilience that may stand in the way of their integration (see Fig. 8). These include aiming for different goals, having different assumptions of normality, different approaches in pursuing their objectives, having different research focuses, and putting emphasis on different values [12,19,29]. Moreover, some critiques of the resilience of social-ecological systems, such as Le Maitre & O'Farrell [59] argue that human-engineered resilience ultimately fails due to two reasons. Firstly, it locks social and economic systems in specific states and trajectories (as in the case of market mechanisms, development of technologies and governance methods) that reduce resilience. Secondly, it also reduces the resilience of the ecosystems that support the social and economic system components to the point that essential services required by society and other populations can no longer be delivered, i.e., climate change and freshwater availability [29,59].

4. Discussion

The concepts of sustainability and resilience are multidimensional, and therefore have various aspects of them treated separately in different disciplines. Previous studies have shown different possible connections between sustainability and resilience paradigms. This, to a great extent, depends on the area and the scale in which the two concepts are studied. Four major themes in the relationship between sustainability and resilience include:

1. The two concepts are considered synonyms and used almost interchangeably (Fig. 9a).
2. The concept of resilience is considered a component of sustainability (Fig. 9b).
3. The concept of sustainability is considered a component of resilience (Fig. 9c).
4. The two concepts are regarded as separate yet complementary conceptual objectives (Fig. 9d).

The importance of understanding the relationship between sustainability and resilience is more pronounced in light of the increasing frequency of natural hazards due to the effects of climate change [6,27,57]. Despite acknowledging such a close bond between two concepts, the research indicates a lack of a unifying framework for sustainability and resilience. Some previous studies have recommended the integration of sustainability and resilience in building design and assessment, and claimed this integration serves to "(1) conserve future resources, (2) protect investment in sustainable structures and infrastructure, (3) ensure that sustainable developments continue to function for their design life and continue to reap the benefits of sustainable design, and (4) preserve the stability of social and economic networks within communities" [4]. Some efforts for proposing the generation of

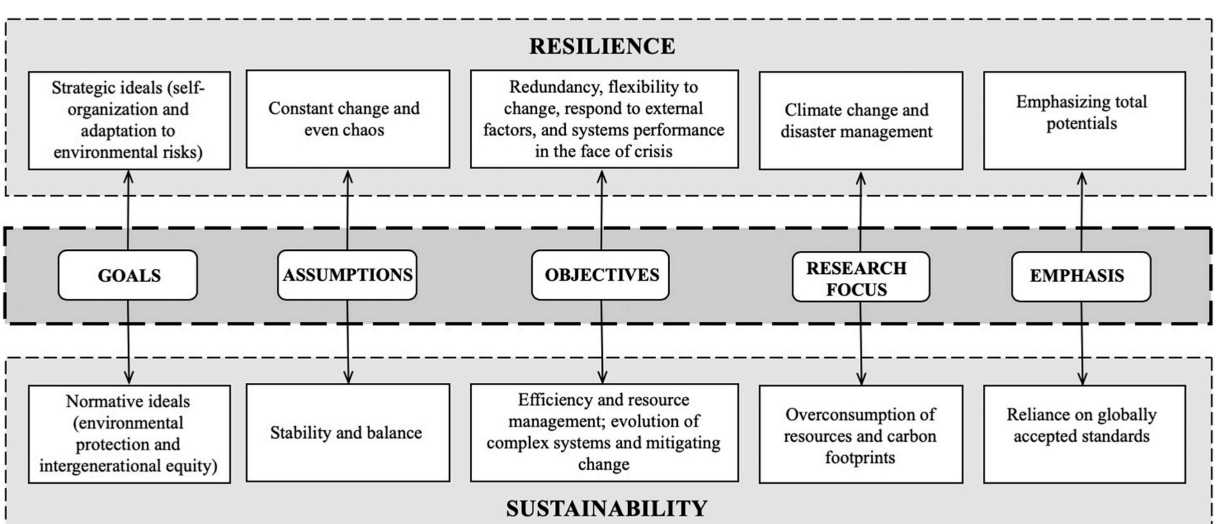

Fig. 8. The tensions between sustainability and resilience (Data from Refs. [12,19,29].

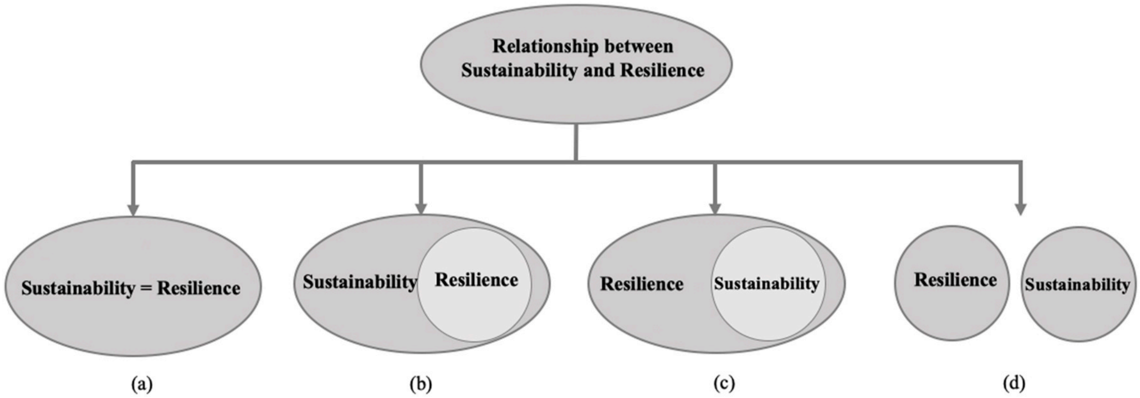

Fig. 9. Different relationships between sustainability and resilience.

such a framework identify the process to be technically possible, citing the experience of countries such as Japan and Germany.

A set of challenges between the two concepts has also been revealed and may obstruct this integration (i.e., having different goals, different approaches in achieving their goals, having different views of equilibrium as well as focusing on different values). Some opponents of resilience argue that resilience does not always imply a normatively positive nature or a desired state, because a system could be highly resilient without achieving sustainability goals, e.g., system states that decrease social welfare, such as polluted water supplies or dictatorships, can also be highly resilient [29]. Also, the effectiveness of one resilience strategy could be at the expense of total efficiency, and consequently the sustainability of the building [60]. Therefore, making some compromises seems necessary when some of the sustainability or resilience objectives are in conflict with one another. Others have condemned human-engineered resilience to failure [59]. As Folke [26] states, resilience is a dynamic concept that is not only about persistence to change, but also has to do with evolving with change. Considering adaptation as a "process of deliberate change in anticipation or in reaction to external stimuli and stress" [26,61]; it is a characteristic of ecological systems and therefore cannot be applied to buildings and man-made structures as they do not have the ability of self-adjustment. Therefore, borrowing an ecological terminology –resilience– and applying it to buildings serves more like a "metaphor" or a "perspective" [17]. In this regard, resilience as Brand and Jax [17] argue, is becoming a "boundary object" like sustainability, which "facilitates communication across disciplinary borders by creating a shared vocabulary, although the understanding of the parties would differ regarding the precise meaning of the term in question." Sustainability and resilience are also known and criticized for being malleable concepts [17,62]. This malleability has many attractions for various disciplines and allows for different interpretations across different domains. It is also what makes boundary objects politically successful in reconciling contrasting interests of different disciplines such as science, engineering, and policy [17].

Needless to say, sustainability maintains its dominant role as the preferred development paradigm for most policy and program actions taken by governments, communities, and businesses today [63] (Fig. 10). And whether we like it or not, a movement has already been initiated to incorporate resilience measures into the sustainable development framework. For example, the USGBC formally adopted the resilience consensus standard, RELi, to become a global rating system under the USGBC's rubric. As a product of Greenbuild 2017 Conference, RELi is a comprehensive rating system that works synergistically with LEED to better withstand shocks and stressors like extreme weather, sea level rise, social and economic volatility, and resource shortages [64].

Additionally, Envision V3 has pushed for resilience and has changed the "Climate and Risk" category to "Climate and Resilience" with 2 subcategories and 10 credits. The resilience subcategory includes: "Avoid Unsuitable Development," "Assess Climate Change Vulnerability," "Evaluate Risk & Resilience," "Establish Goals and Strategies," "Maximize Resilience" and "Improve Infrastructure Integration." Currently, there is no data available to show the level of resilience adoption in the building industry. However, the level of resilience research activities in recent years has shown a continuous increase (see Fig. 11).

Although most existing studies stress the ecological aspect of resilience, only by considering human involvement in the process can resilience thinking inform sustainability in a meaningful way [29]. This is due to the fact that in the context of the built environment, engagement of all stakeholders, including technical, strategic, social and political parties is required.

5. Conclusion

As the concept of resilience is becoming increasingly important in sustainable development, some concerns are arising around the idea of combining resilience and sustainable assessment frameworks. This study explored definitions and relationships between the concepts of sustainability and resilience, as well as the challenges of establishing a building assessment framework to embrace the two. Given the complexity surrounding the issues of sustainability and resilience and the differences between their definitions, methodology, and areas of applicability, proposing a single framework to fully integrate the two concepts is very challenging. Clearly, there is no such thing as a one-size-fits-all approach when it comes to incorporating resilience standards into the sustainability agenda. The combined framework must be tailored and customized to fit the case-by-case nature of projects, based upon the location, climate, and type of natural hazards to which the area is vulnerable. The integration process also requires an the active involvement of different stakeholders in all stages. Furthermore, one cannot simply delve into the sustainability assessment frameworks such as LEED and search for indicators of resilience, because those assessment systems are not primarily designed to include resilience indicators. Therefore, in order for sustainability assessment systems to integrate resilience indicators, development of new systems or a thorough refinement of current systems seem inevitable. Future research work will focus on the context of existing sustainability and resilience strategies and assessment tools to properly conceptualize and develop a combined coherent framework. Examples of buildings which incorporated both sustainability and resilience indicators in their designs, such as the Salt Lake City Public Safety Building in Utah will also be studied (Fig. 12).

Declarations of interest

None.

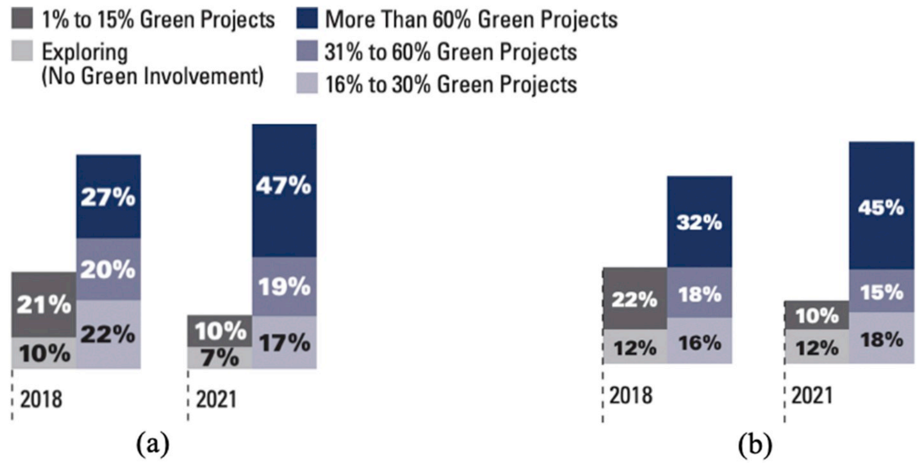

Fig. 10. (a) Global level of green building activity in 2018 and 2021 expected. (b) Level of green building activity in the US in 2018 and 2021 expected. Source: [18]. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

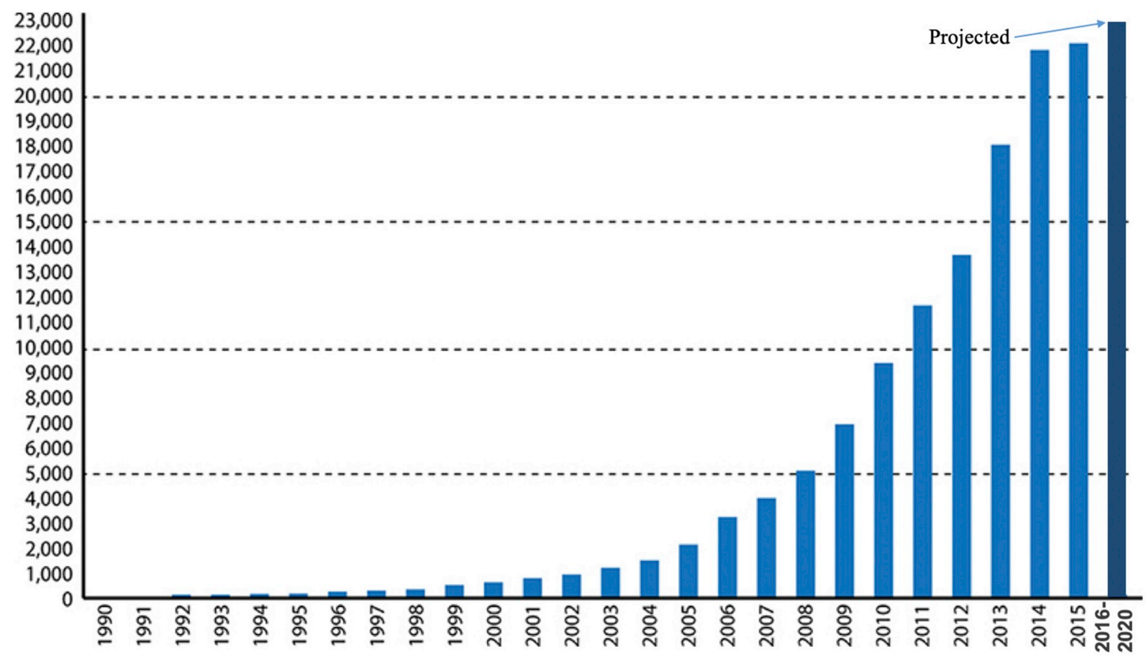

Fig. 11. The number of annual citations attributed to resilience (modified from Ref. [26].

Fig. 12. The Salt Lake City Public Safety Building, in Utah, is a LEED Platinum certified building which also meets seismic and ballistic requirements. Photo: Dana Sohm | Sohm Photografx, courtesy of GSBS Architects.

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